

## “Optical Quantum Computer” for the New Era of Computing

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Fig. 1: Optical quantum computer in the laboratory.

The picture is provided by Assoc. Prof. Shuntaro Takeda.

Have you ever heard of “Chat GPT”? Many people may answer “Yes”! As shown in this example, the importance of computer calculation gets higher and higher day by day. Other than Chat GPT, you may use a smartphone, personal computer, and so on. Hence, it is needed for computers to calculate rapidly and with low energy. To achieve this purpose, much effort has been paid, and the performance of computers has been improved. However, this improvement is about to reach the limit. According to Moore’s law, “the complexity for minimum component costs has increased at a rate of roughly a factor of two per year [1]”, and the performance of computers has been improved, obeying this rule. However, in recent years, the development has gradually slowed down.

The demand for computer performance is getting large and large, but development is getting slowed down. How do we solve this conflict? The answer may

be “Quantum Computer”. Quantum computers may be able to solve problems efficiently and with low energy, so many researchers are interested in Quantum computers and study diligently. If a quantum computer is realized, it will be useful in various fields such as optimizations, pharmaceuticals, and cryptography.

Quantum computer is a computer that works according to “quantum mechanics”, the mysterious laws. There are two mysterious points in quantum mechanics. The first is the “superposition”, and the other is the “entanglement”. I will first talk about “superposition”. In the usual computers, we implement calculation by using two numbers: zero and one. However, in quantum computers, we implement calculation by using the “superposition” of zero and one. The “superposition” seems like zero and one exists at the same time as Ninja’s shadowy alter-ego. The fact that shadowy-alter-ego states actually exist is, in the first place, surprising! In addition to this, we can calculate problems efficiently by using these mysterious states. The principle is that we can handle alter egos simultaneously and proceed with calculations in parallel. Precisely speaking, we cannot handle or read alter egos separately, but we can move to overall alter egos toward the right place. I will then talk about the second mysterious point “entanglement”. In quantum mechanics, we can make a correlation between two objects, even if the objects are away from each other. By using this correlation, we can handle complex problems by letting many objects correlate with each other, or we can even “teleport” one’s information to another. Such operations are only implemented in quantum computers, so quantum computers may become strong tools for the next generation of computers.

How can we make quantum computers? Many method has been invented such as the superconducting quantum computer and the ion-trap quantum computer.

However, in recent years, quantum computers using “light” attracts attention. Light has many merits to use. First, light is fast. Because light is fast and the frequency of light is very high, we can implement calculation very rapidly in principle. Second, light can be used at room temperature. Quantum mechanics is a very mysterious law, and the quantum nature is generally prominent at low temperatures. However, we can use light at room temperature (very high temperature compared to the superconductor and so on) because light has high energy, and the energy at room temperature can be negligible. Moreover, optical quantum computers do not consume any energy in principle. For this reason, optical quantum computers are ecologically friendly and we can use optical quantum computers sustainably even if the demand for computers increases in the future.

More recently, the other feature of light has been paid attention. That is, optical quantum computers can handle arbitrary real numbers efficiently. The usual computers use two discrete variables; zero and one to implement computation. In this sense, the usual computers can be regarded as “digital” computers. In contrast to this, optical quantum computers which are studied recently can handle arbitrary real numbers, not restricted to zero and one. In this sense, optical quantum computers can be “analog” computers. There are many merits to analog computers. First, there are a lot of problems that can be written in analog (continuous) variables. For example, the quadratic function people learn in junior high schools is a problem written by continuous variables. Analog computers can solve these problems efficiently, so analog computers can enhance the types of problems that can be solved with computers. Moreover, analog computers have immunity to errors if we encode digital information to analog variables. Computers are made up of real materials, so computers cannot avoid errors while calculating. For this

reason, if we want to make computers that calculate problems precisely and has no errors, we have to consider correcting errors. Because continuous variables can have a lot of information compared to discrete variables, we can correct errors by using plenty of information. For these reasons, continuous-variable optical quantum computers have been paid attention these days.

In this essay, I introduce the attraction of quantum computers, and the merits of “optical”, and “continuous-variable” quantum computers. However, this method has many problems and is far from complete. For example, quantum computers nowadays are so small that we cannot solve large-scale problems, and has a large degree of errors. I expect the next-generation scientists to solve the problems of scalability and errors, and achieve the perfect Quantum computer!

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### References

[1] "Cramming more components onto integrated circuits", Electronics Magazine 19 April 1965

### **【Tools I used while writing 】**

I used “DeepL” and “Grammarly” while writing. I used “DeepL” to look up expressions in English. I used “Grammarly” to check the grammar of the main text.